

Seismic Fragility Curves of URBM Building – A Sensitivity Analysis

Kodiswari V.^a, Balasubramanian S. R.^b, N. Sakthieswaran^c, A. Meher Prasad^d, P. Sivakumar^e

^aM.E. Student, Regional Centre of Anna University, Tirunelveli, INDIA

^bScientist, CSIR-Structural Engineering Research Centre, Chennai, INDIA

^cAssistant Professor, Regional Centre of Anna University, Tirunelveli, INDIA

^dProfessor, IIT Madras, Chennai, INDIA

^eChief Scientist, CSIR-Structural Engineering Research Centre, Chennai, INDIA

Abstract - Seismic fragility analysis of Unreinforced Brick Masonry (URBM) buildings is useful for determining the possible extent of damage in the event of an earthquake. There are uncertainties associated with mechanical properties of masonry and also the characteristics of earthquake ground motion. This paper discusses the results of parametric studies carried out by varying the values of Coefficient of Variation (COV) of compressive strengths of brick and mortar, and, by using 12 different earthquake time histories available in the strong motion atlas of India. For this purpose a one room, single storey URBM building has been considered and the fragility curves have been obtained in accordance with the procedure proposed earlier. From this study, it is noted that fragility curves of URBM buildings are not significantly affected by the COV of brick and mortar strengths whereas they are sensitive to the choice of earthquake time histories.

Keywords: Unreinforced Brick Masonry; Seismic Fragility Curves; Coefficient of Variation; Sensitivity Analysis; Lognormal Distribution; Incremental Dynamic Analysis.

I. INTRODUCTION

Earthquakes are a major threat to the world and every life depends upon the buildings and structures. Among the various types of building unreinforced brick masonry buildings (URBM) are responsible for the highest proportion losses of life worldwide and are one of the most vulnerable types of buildings when subjected to earthquakes. Unreinforced brick masonry is widely used and most common in developing and under developed countries. However, the majority of these buildings are generally composed of low-engineered buildings which have not been adequately designed to resist earthquake forces. Total collapse of walls and entire buildings of brick masonry during Bhuj 2001 earthquake shows that URBM is vulnerable. India has more than fifty percent of land area liable to earthquakes and about 45% of existing masonry buildings. Hence evaluation of seismic vulnerability is necessary. Seismic vulnerability analysis of Unreinforced Brick Masonry (URBM) buildings is useful for determining the possible extent of damage in the event of an earthquake and hence the assessment of seismic vulnerability of URBM buildings has practical significance. This study deals with the sensitiveness of uncertainties that is considered in vulnerability analysis.

II. SOURCES OF RANDOMNESS IN VULNERABILITY ANALYSIS

Earthquake prone areas are subjected to many uncertainties in randomness of ground motion (characteristics of earthquake ground motions) and also in mechanical properties of brick masonry. Several researchers have done sensitivity analysis on quantifying the model parameter uncertainty in assessment. Sensitivity analysis is used to infer the relative independent random variables. Simulation based methods are used for uncertainty propagation which is easy to implement and when sample increases to converge it to exact solution [1]. In this study Monte Carlo Simulation is used for simulating variables. Seismic assessment of masonry structures has both inherent (aleatory) randomness and model (epistemic) uncertainty. Also, assessment of the propagation of uncertainty from the material properties to seismic capacity of an entire masonry structure is proposed by Parisi [2]. Baker and Cornell [3] have proposed some approaches to characterize uncertainties in ground motion hazard, building response and damage to building components. Uncertainties in strong-motion modelling can be explicitly related to the uncertainties in few basic model variables namely Moment magnitude, distance to fault, depth, fault radius, shear wave capacity, density and spectral decay [4]. Uncertainty in mechanical properties is handled by taking Compressive strength of brick (f_b), Compressive strength of mortar (f_m), Bed-joint friction coefficient (μ) as statistically independent random variables whereas Compressive strength of masonry (f_M), Elastic modulus of masonry (E_M), Shear bond strength of masonry (f_{vo}), Tensile strength of masonry (f_t) are taken as mechanically dependent random variables with log normal distribution as candidate distribution and simulating it to 1,00,000 realizations and also Characteristics of earthquake ground motion are dealt by considering 12 earthquake time histories from the strong atlas motion of India in which both near field and far field earthquakes are considered together [5].

III. SENSITIVITY ANALYSIS OF SOURCES OF RANDOMNESS IN MECHANICAL

PROPERTIES AND CHARACTERISTICS OF EARTHQUAKE GROUND MOTION

The mechanical properties used in this study are tabulated as in Table. 1 and Table. 2. The methodology integrating improved storey shear modelling, Monte Carlo Simulation (MCS) and Incremental Dynamic Analysis (IDA)

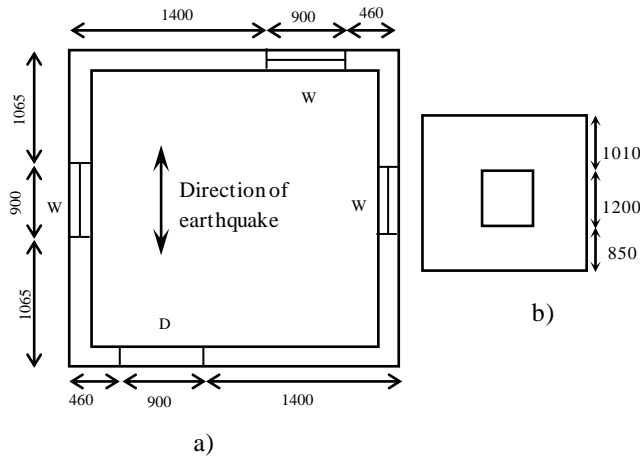


Fig. 1 Geometry of a) Brick masonry building [7] b) in-plane walls
(All the dimensions are in mm)

From the sensitivity analysis with respect to characteristics of earthquake ground motion the material property has same mean values as in Table. 1 but the Coefficient of variation is taken as 0.20 for compressive strength of brick and 0.10 for compressive strength of mortar. The salient features of the 12 earthquake time histories considered in this study are listed in Table. 3.

Three types of damage grades used in literature [5] is considered in this study are DG1 corresponding to 33% of yield point of the building, DG2 corresponding to yield point of building and DG3 corresponding to the collapse of the building. A similar work with Weibull distribution as candidate distribution for statistical variations in mechanical properties of masonry has been carried out at CSIR-SERC [11].

is used [5]. Coefficient of Variation of compressive strength of brick is taken as 0.10, 0.15, 0.20 and 0.25 one by one where as for mortar 0.05, 0.10, 0.15 and 0.20. 16 fragility curves were plotted by changing the Coefficient of variation of compressive strength of brick and mortar. Unreinforced Brick Masonry Building (URBM) considered in the study is shown in Fig. 1.

Table. 1 Material Properties considered in this Study as Statically Independent Random Variables [4]

Sl. No	Parameter	Mean value	Coefficient of variation (COV)
1.	Compressive strength of brick, f_b	24.2 MPa [7]	Varied between 0.10 to 0.25
2.	Compressive strength of mortar, f_m	5.9 MPa for portion above lintel [7] 2.1 MPa for portion below Lintel [7]	Varied between 0.05 to 0.20
3.	Bed-joint friction coefficient, μ	0.4 [8]	0.10

Table. 2 Material Properties considered in this Study as Mechanically Dependent Random Variables [4]

Sl. No	Parameter	Mean value
1.	Compressive strength of masonry, f_M	$0.63 f_b^{0.49} f_m^{0.32}$ with a modelling error 'e' which is an independent random variable assumed to have a normal distribution with COV- 0.10 [9]
2.	Elastic modulus of masonry, E_M	$250 f_M$ referred from [9]
3.	Shear bond strength of masonry, f_{vo}	$f_{vo} = 0.0484 f_M^2 - 0.1651 f_M + 0.2841$ referred from [10]
4.	Tensile strength of masonry, f_t	$f_t = 0.0346 f_M^2 - 0.0991 f_M + 0.1546$ referred from [10]

Table. 3 Earthquake Time Histories considered in the Study [5]

Sl. No.	Earthquake [Magnitude, m_b]	Date	Recording station direction	R (in km)	NF/FF	PGA (in g)
EQ1.	Dharmasala Earthquake [5.5]	26/04/1986	Shahpur (32.21° N, 76.19° E) T, 165°	9.98	NF	0.248
EQ2.	North-East India Earthquake [5.2]	10/09/1986	Saitama (25.72° N, 92.39° E) T, 175°	44.79	FF	0.139
EQ3.	India-Burma Border Earthquake [5.7]	18/05/1987	Diphu (25.92° N, 93.44° E) L, 90°	105.03	FF	0.086
EQ4.	India-Bangladesh Border Earthquake [5.8]	06/02/1988	Nongkhlaw (25.69° N, 91.64° E) T, 170°	116.27	FF	0.114
EQ5.	India-Burma Border Earthquake [6.8]	06/08/1988	Diphu (25.92° N, 93.44° E) T, 180°	189.94	FF	0.337
EQ6.	India-Burma Border Earthquake [6.1]	10/01/1990	Berlongfer (25.77° N, 93.25° E) L, 256°	230.01	FF	0.145
EQ7.	Uttarkashi Earthquake [6.5]	10/10/1991	Uttarkashi (30.73° N, 78.45° E) T, 345°	32.52	FF	0.39
EQ8.	Chamba Earthquake [4.9]	24/03/1995	Chamba (32.55° N, 76.12° E) T, 0°	8.2	NF	0.146
EQ9.	India-Burma Border Earthquake [6.4]	06/05/1995	Diphu (25.92° N, 93.44° E) T, 180°	215.91	FF	0.102
EQ10.	India-Bangladesh Border Earthquake [5.7]	10/05/1997	Jellalpur (25.00° N, 92.46° E) T, 2°	24.45	FF	0.138
EQ11.	Chamoli Earthquake [6.4]	29/03/1999	Gopeshwar (30.40° N, 79.33° E) T, 20°	8.70	NF	0.359
EQ12.	Kachchh Earthquake [7.0]	26/01/2001	Ahmedabad (23.03° N, 72.63° E) T, 78°	238	FF	0.106

T-Transverse direction; L-Longitudinal direction; R-Epicentral distance as referred in Atlas of Indian Strong motion records; true bearings are as obtained from internet (Cosmos) ; NF-Near Field earthquakes; FF-Far Field earthquakes

IV. RESULTS AND DISCUSSIONS

Smoothened fragility curves were developed for the considered building and they have been presented below.

- 1) Fig 2. a) - p) represents the fragility curves with variation in COV of Compressive strength of brick and mortar. These curves are plotted with multi record IDA.

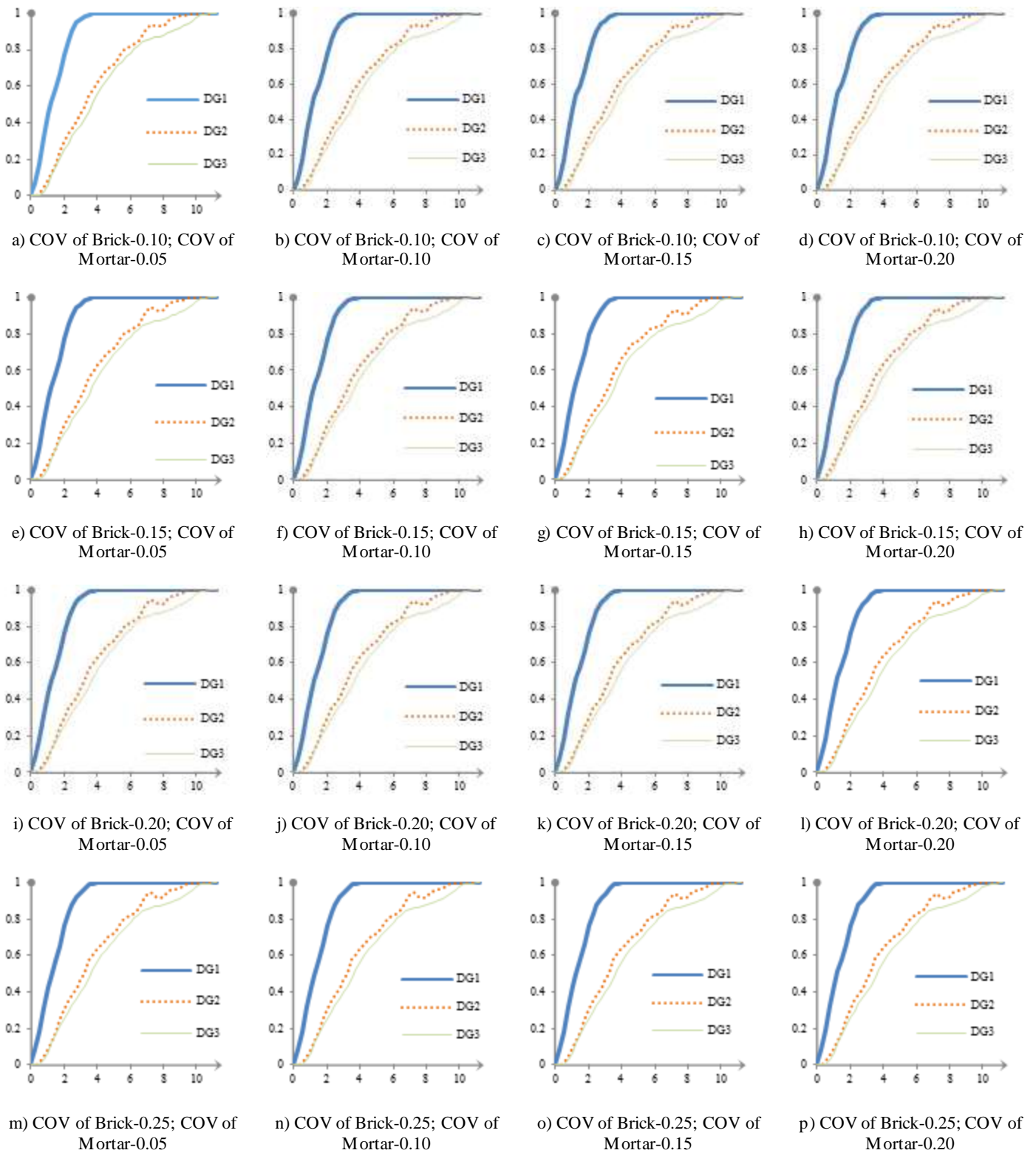


Fig. 2 Fragility curves for different COVs of Compressive strength of Brick and Compressive strength of Mortar
 (X axis: Intensity Measure- PGA (in m/sec^2); Y axis: Fragility)

2) A typical comparison of fragility curves is shown in Fig 3 where Coefficient of variation (COV) of compressive strength of brick is taken as constant value 0.15 and Coefficient of variation (COV) of compressive strength of mortar is varied.

- i. From Fig. 3 a), Fragility against DG1 is observed to be initiated at 0.25 PGA and reaches unity at 5.75 PGA.
- ii. From Fig. 3 b), Fragility against DG2 is observed to be initiated at 0.375 PGA and reaches unity at 9.75 PGA.

iii. From Fig. 3 c), Fragility against DG3 is observed to be initiated at 0.5 PGA and reaches unity at 10.75 PGA.

- 3) It is observed that the when COV is 0.15 for both compressive strength of brick and mortar are same the fragility curve slightly differ from fragility curves with other COV.
- 4) Thus, from the results obtained it shows clearly that fragility curves are not much sensitive to the Coefficient of variation of strengths of brick and mortar.

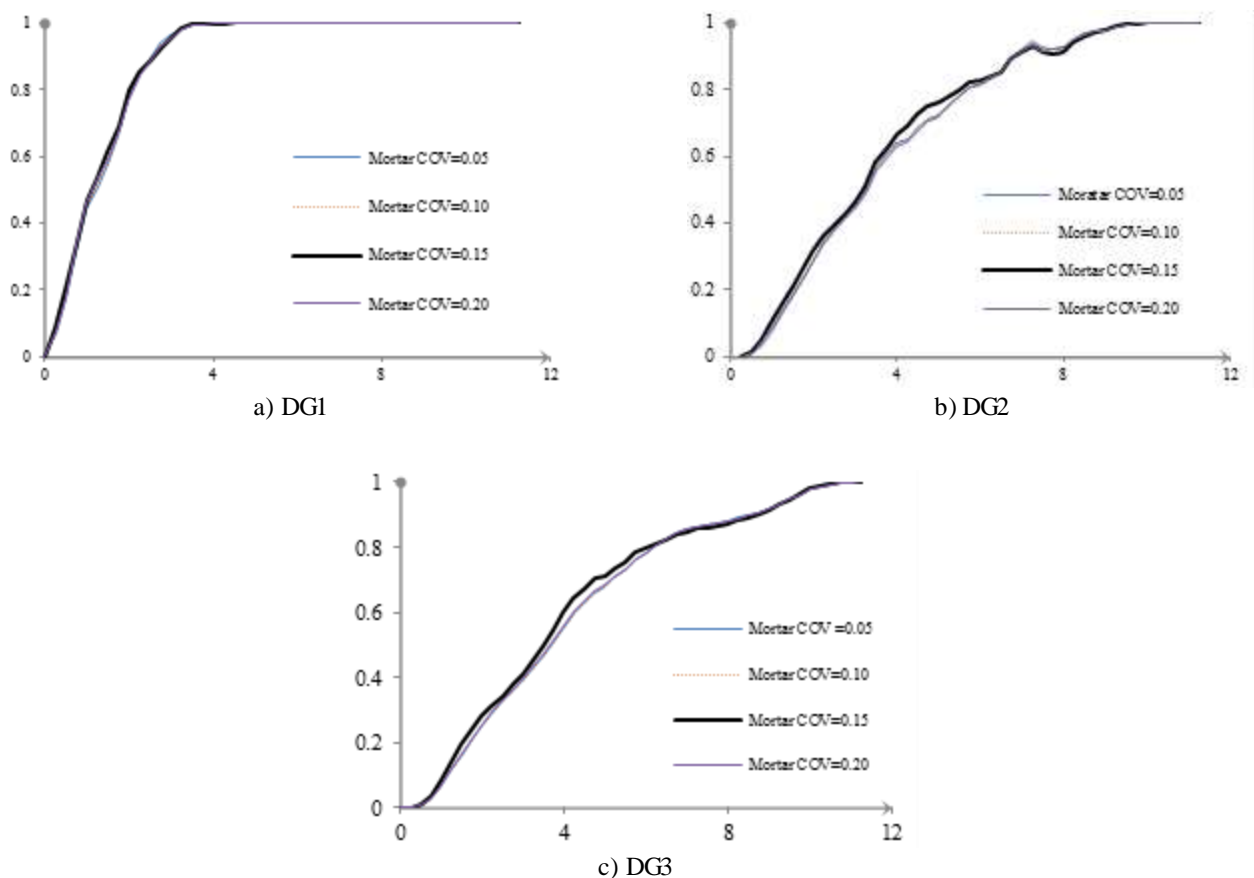


Fig. 3 Fragility curves for constant COV of 0.15 for brick and varied COV of Mortar
 (X axis: Intensity Measure- PGA (in m/sec^2); Y axis: Fragility)

When choice of earthquake ground motions is considered the resulted fragility curves using 12 earthquakes with magnitudes (m_b) ranging from 4.9 to 7 for DG1, DG2 and DG3 are presented in Fig. 4 a), b) and c) respectively.

5) It is observed that fragility curves show three clusters of curves in all damage grades. This cluster is same for three damage grades.

- i. First cluster has EQ3, EQ5, EQ6, EQ9 and EQ12 earthquakes.

ii. Second cluster of curves has EQ1, EQ2, EQ4, EQ7 and EQ8;

iii. Third cluster has EQ10 and EQ11.

- 6) This grouped fragility curves are dependent on the epicentral distance of earthquakes. First cluster of earthquakes has greater epicentral distance, second cluster shows a medium far field earthquake and third one has a smaller epicentral distance.

- 7) Also it is observed that all India-Burma Border earthquake forms the cluster one and others vary.
- 8) For first cluster of curves in DG1 from Fig. 4 a) it is observed that the commencement of damage occurs at 0.01g and attains unity at 2; for second cluster initiation was found at 0.5 PGA and reaches unity after 3.25 PGA;
- 9) In DG2 and DG3 the initiation of second and third band of curves were at greater PGA comparing to first band of curves.

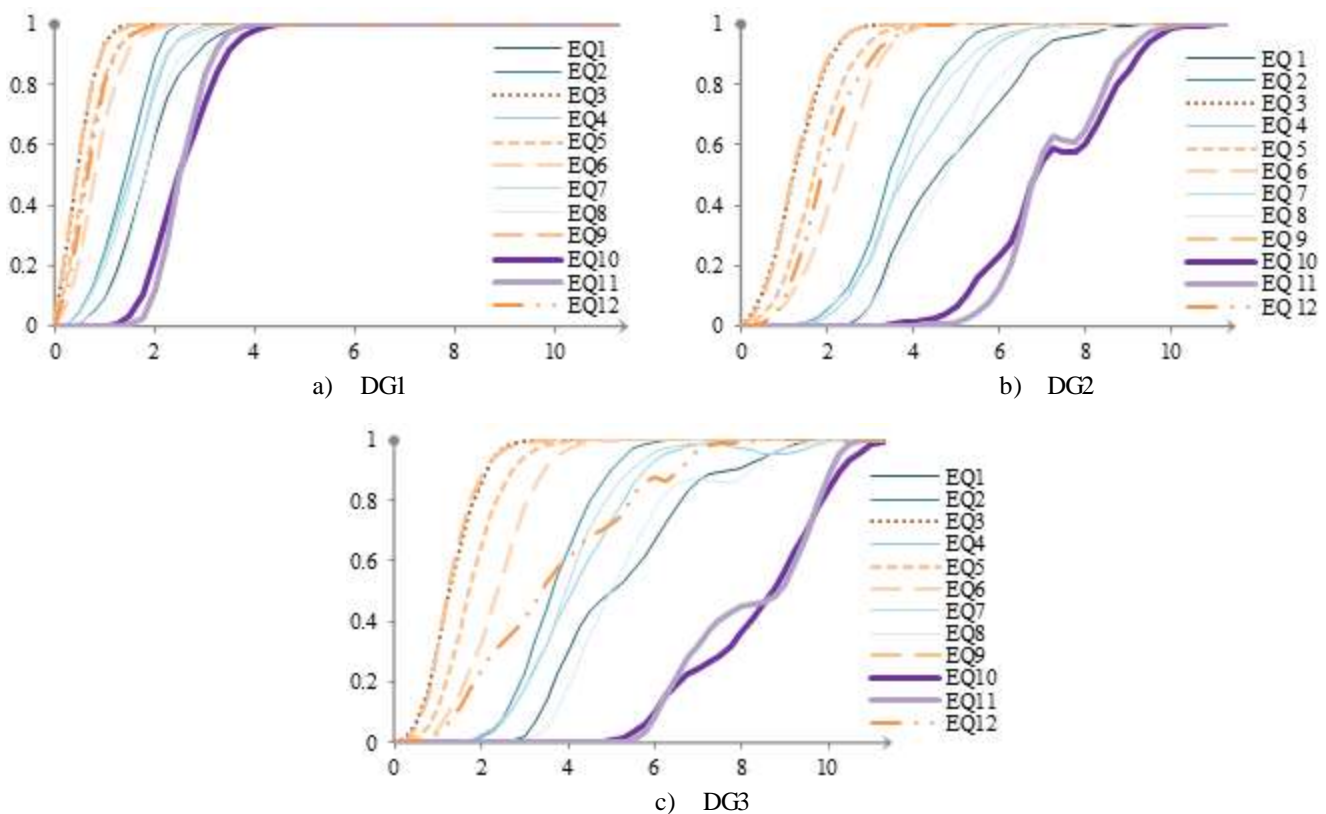


Fig. 4 Fragility curves as obtained using Single-Record IDA for 12 earthquake time histories
 (X axis: Intensity Measure- PGA (m/sec^2); Y axis: Fragility)

V. CONCLUSION

This paper discusses the sensitivity analysis of uncertainties in development of fragility curves for URBM buildings. From the sensitivity analysis, it is noted that the fragility curves are not significantly affected by the statistical variations in mechanical properties of masonry. On the other hand, as expected, the details of earthquake time histories [5] considered for IDA significantly affect the fragility curves for URBM buildings. Thus, a proper selection of suite of earthquake time histories plays significant role in establishing the safety of URBM buildings. Since, in India there are different seismogenic regions [12], there is a need to develop suite of earthquake time histories for the respective regions in order to evaluate and to ensure the safety of URBM

buildings.

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